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Dr. Lee, President, in the Chair.

E. D. Johnson, Esq., 9 Wilmington Square;
Rev. R. C. Lumsden, Sheffield;
Basil Woodd Smith, Esq., Hampstead; and
R. C. May, Esq., Great George Street, Westminster,

were balloted for and duly elected Fellows of the Society.

On the Light of the Sun, Moon, Jupiter, and Venus. By G. P. Bond, Director of the Observatory of Harvard College.

In a memoir recently communicated to the American Academy of Arts and Sciences I have given an account of experiments made at the Observatory, during the past year, upon the light of the Sun, Moon, *Jupiter*, and *Venus*. Attention was originally directed to the subject by the remarkable photographic intensity of the light of *Jupiter*, which was first noticed in March, 1851. This property has also been recognised by Mr. De La Rue, who has described his experiments in the *Monthly Notices* of the Royal Astronomical Society, vol. xviii. p. 55. I have found that the reflective capacity of the surface of *Jupiter* for the photographic rays is fourteen times greater than that of the Moon: in other words, out of

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an equal quantity of light incident upon each of the two bodies *Jupiter* reflects fourteen times more of the chemical rays than the Moon does. Hence we have,

$$\frac{\text{Photographic albedo of Moon}}{\text{Photographic albedo of Jupiter}} = \frac{1}{14}.$$

I am satisfied that no considerable difference of colour, such as has been supposed by De La Rue, exists in the light of the two bodies—certainly none sufficient to account for their very unequal chemical action. From several trials made for the purpose, it would seem that the reflective capacity of the Moon's surface for the photographic rays is not inferior to that of the objects which give the prevailing tone of light to a landscape-view on the earth. On the other hand, no opaque substance has been found capable of reflecting light sufficient to act upon the plate with the same rapidity as *Jupiter*, when the illumination to which both objects are exposed is reduced to the same intensity.

The experiments, though liable to the uncertainty incident to all photometric measurements, are sufficient to prove an excess of photographic intensity in the light of the planet not susceptible of any ready explanation. They have suggested a series of comparisons of the optical intensity of the light of the bodies in question, which have led to the conclusion that the whiteness (*albedo*) of the surface of *Jupiter* exceeds that of any known opaque substance. Even the dusky belts give more light than an equal area of new-fallen snow would do if exposed to the same intensity of solar illumination. The fact is the more remarkable from the circumstance that occasionally white streaks and minute bright spots have been seen upon its disk much more brilliant than the general surface.

In a question where disturbing influences so easily mislead the judgment, it is desirable to bring together the results of different methods of examination. The following affords, perhaps, the most decisive confirmation of the fact of the superior brilliancy of *Jupiter*. I have found, from my own observations, the photometric proportion

$$\frac{\text{Jupiter at mean opposition}}{\text{Mean full Moon}} = \frac{1}{6430},$$

which is confirmed by the results of Sir J. F. W. Herschel's valuable collection of photometric comparisons made at the Cape of Good Hope, giving

$$\frac{\text{Jupiter at mean opposition}}{\text{Mean full Moon}} = \frac{1}{6620}.$$

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This is derived, not from actual comparisons of *Jupiter* and the Moon, but indirectly from the ratio

$$\frac{\alpha\ \text{Centauri}}{\text{Mean full Moon}} = \frac{1}{41400},$$

differing from Herschel's result published in his *Outlines of Astronomy*, principally on account of a change introduced into the corrections applied to the light of the several phases of the Moon to reduce them to the full phase, which will be more fully explained presently. For the relation between *α Centauri* and *α Lyræ*, we have

$$\text{Log.}\ \frac{\alpha\ \text{Centauri}}{\alpha\ \text{Lyræ}} = 0{\cdot}1200,$$

derived from determinations by Seidel and Herschel. Seidel* has obtained, from a very complete discussion of the subject, the values

$$\text{Log.}\ \frac{\text{Sun}}{\alpha\ \text{Lyræ}} = 10{\cdot}4499 - \text{log. albedo Jupiter},$$

$$\text{Log.}\ \frac{\text{Jupiter at mean opposition}}{\alpha\ \text{Lyræ}} = 0{\cdot}9158.$$

From the above numbers we obtain

$$\text{Albedo of Jupiter} = \frac{532000}{S}$$

where S is the ratio between the light of the Sun and of the mean full Moon. If, now, we substitute in this last result the value

$$S = 550000,$$

which is the mean between the determinations by Bouguer and Wollaston, we find

$$\text{Albedo of Jupiter} = 0{\cdot}967,$$

or more than double that attributed by Lambert to a surface of the finest white lead (cremnitz white), which gave the highest albedo, viz., 0·423, of any substance experimented upon by him.

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* Untersuchungen über die Lichtstärke der Planeten *Venus*, *Mars*, *Jupiter* und *Saturn*. 4° Munich, 1859.

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The values attributed to S by Bouguer and Wollaston, viz.,

$$S = 300{\cdot}000 \text{ by Bouguer,}$$
$$S = 810{\cdot}072 \text{ by Wollaston,}$$

are certainly very discordant, though not more so, perhaps, than the difficulties attending the subject would lead us to expect. A new determination, which I have made by a method differing from those employed by them, gives

$$S = 470{\cdot}980.$$

I have made use of the Bengola light as an intermediate standard of comparison, the colour of its light agreeing very closely with that of moonlight. The observations upon the intensity of moonlight give

$$\text{Albedo of Moon} = \frac{45{\cdot}193}{S}$$

$$\text{,,} \quad \text{,,} \quad = \frac{1}{12{\cdot}2} \text{ for } S = 550{\cdot}000,$$

$$\text{,,} \quad \text{,,} \quad = \frac{1}{10{\cdot}4} \text{ ,, } S = 470{\cdot}980,$$

for the relative albedos of the Moon and *Jupiter*.

$$\frac{\text{Albedo of Moon}}{\text{Albedo of Jupiter}} = \frac{1}{11{\cdot}47},$$

and, consequently, for *Jupiter* an albedo of very nearly unity, if we take $\frac{1}{11}$ as the albedo of the Moon. Thus all the data indicate a remarkable excess of brilliancy in the light of *Jupiter*.

For the relative albedos of *Venus* and *Jupiter*, I have found the proportion $\frac{1}{1{\cdot}10}$. Seidel gives $\frac{1}{1{\cdot}044}$ for the same ratio. I am inclined to think, however, that the albedo of *Venus* is, in both instances, estimated too high, since it depends mainly upon observations made near the epoch of greatest brilliancy, or between that point and the inferior conjunction, where the illuminated phase occupies but a small part of the disk. The line of incidence and reflection thus approaches the direction of a tangent to the surface; and, as a necessary consequence, the tendency to regular reflection in an opaque surface so presented will have the effect of increasing the quantity of light received from the crescent phases, especially as the planet approaches inferior conjunction.

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It is not possible to estimate the amount of light regularly reflected; but there can be no doubt that Lambert's phase-formula, which has been employed in the reductions, will give, on this account, a sensibly higher albedo from observations at the narrow crescents than would be obtained from other phases.* Seidel's observations contain a confirmation of this inference.

In comparing the light of the Moon with the light emitted through a small aperture in a screen placed in front of the flame of a Carcel lamp, arranged with a view to secure a constant standard of illumination, I have obtained the following values of the logarithms of the quantity of light received from its various phases: v represents the angle of elongation of the Moon from the Sun, and H_0 the relative quantity of moon-light from the corresponding phase, taking the light of the mean full Moon as the unit.

$v =$ 0°	Log. H_0 =	$-\infty$
20	,,	7·224
40	,,	8·049
60	,,	8·574
80	,,	8·974
100	,,	9·291
120	,,	9·551
140	,,	9·763
160	,,	9·931
180	,,	= 0·000

The observations have been freed from the effect of atmospheric extinction, and reduced to the mean distance of the Moon from the Earth and Sun.

Herschel's photometric observations made at the Cape of Good Hope upon the light of the Moon and of various fixed stars have furnished, after reduction, the following comparisons with value of log. H_0 taken from the above table —

	Log. H_0.	Cape Obs.	Diff.	Wt.
$v =$ 102·2°	9·324	9·368	−0·004	7
121·7	9·574	9·560	+0·014	8
131·3	9·681	9·711	+0·030	9
135·7	9·724	9·725	−0·001	9

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* It is well known that *Venus* is visible in the day time to the naked eye, at near the time of its greatest brightness. I have often seen *Jupiter* with the naked eye while the sun was high above the horizon and shining clearly; and, on one occasion, *Sirius*. From the readiness with which the latter could be discerned, in a position where much of its light must have been lost by atmospheric extinction, I should think it possible to see *α Lyræ* also under favourable circumstances.

	Log. H_0.	Cape Obs.	Diff.	Wt.
$v =$ 143°·7	9·805	9·778	+0·027	10
158·7	9·920	9·868	+0·052	13
167·0	9·964	9·991	−0·027	6
179·3	0·000	0·157	−0·157	2

With the exception of the last difference, depending upon an isolated observation made under unfavourable circumstances, there is a good agreement between the two series. The present reduction of the *Cape Observations* has been made without regard to Herschel's hypothesis respecting the impression made by the light of the stars upon the eye, as influenced by a change in the illumination of the background of the sky by varying amounts of moonlight, viz., that "the effective impression of a star on the retina is inversely as the square of the illumination of the ground of the sky on which it is seen projected."*

From the manner in which our values of log. H_0 have been obtained, they could not have been affected by this condition; and their accordance with the *Cape Observations*, uncorrected by the hypothesis, shows very clearly that the latter is not necessary to satisfy the observations. And yet it is remarkable that Herschel should have been able, by means of it, to represent completely a large series of observations otherwise wholly discordant. From a full investigation of the subject, the details of which are presented in the memoir, it appears that the true explanation of the discrepancies noticed by Herschel is to be found in the anomalous manner in which the Moon reflects light to the Earth from its different phases, in consequence of which the quantity of moonlight increases much more rapidly towards full-moon, compared with the phases on either side of it, than can be accounted for by the formulæ of Lambert or of Euler—so much so that, taking the full-moon as a standard, even Lambert's, which accords best with observation, makes the observed light at quadrature from two to three times fainter than is indicated by the theory.

Herschel's formula for the relative enfeeblement of the light of the stars, while it affords a very precise representation between quadratures and full-moon, if interpreted as a consequence of an actual variation of the amount of moonlight, is perfectly consistent with the results of my own investigation for the limits including the observations which have been discussed by him.

The following are the results of a comparison of the logarithms of the observed amounts of mean moonlight at different angles of elongation; v, the unit, being the amount from the

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* *Results of Astronomical Observations made at the Cape of Good Hope*, p. 356.

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mean full-moon for which $v_0 = 180^\circ$, with the logarithms computed from the formulæ of Lambert and Euler, and from an empirical formula, in which the light is assumed to vary as $\sin^6 . \frac{1}{2} v$, which differs scarcely sensibly in its results from Herschel's formula under the above construction of its significance. It will be seen that the latter accords well with observation up to about $v = 90^\circ$, and suddenly diverges from a correct representation between new and half-moon, phases which were not included among the *Cape Observations.*

	Obs'd. Moonlight.	Lambert.	Euler and Herschel.	
	Log. H_0.	Log. $\frac{\sin v - v \cos v}{\sin v_0 - v_0 \cos v_0}$	Log. $\sin^2 \frac{1}{2} v$.	Log. $\sin^6 \frac{1}{2} v$.
$v =$ 0	$-\infty$	$-\infty$	$-\infty$	$-\infty$
20	7·224	7·653	8·479	5·438
40	8·049	8·536	9·068	7·204
60	8·574	9·037	9·398	8·194
80	8·974	9·374	9·616	8·848
100	9·291	9·613	9·768	9·305
120	9·551	9·785	9·875	9·625
140	9·769	9·903	9·946	9·838
160	9·931	9·975	9·987	9·960
180	0·000	0·000	0·000	0·000

On the Spiral Structure of the Great Nebula of Orion. By G. P. Bond, Esq., Director of the Observatory of Harvard College.

A disposition in the light of this nebula to radiate outwards and in a southerly direction from the neighbourhood of the *trapezium*, is noticed in my father's memoir, published in 1848, in which are named, as particular localities, Herschel's subnebulous region and the preceding side of the *Regio Huygeniana.* This peculiarity has since attracted attention on many occasions; but it is only recently that it has been subjected to a minute and systematic examination, the results of which I propose now to communicate.

In the season of 1857–58 I undertook the formation of a catalogue of the stars comprised within a square of 40′ having *θ Orionis* as its centre. One hundred and twenty-one of the brighter stars were selected, and their positions determined, to serve as points of reference for filling in the remainder, which were mostly too faint for observation under a strong illumination of the micrometer wires. This was completed in 1858. The order of magnitude of the stars was subsequently made